RESEARCH BULLETIN 681 JULY, 1949

KENTUCKY BLUEGRASS

OHIO AGRICULTURAL EXPERIMENT STATION
Wooster, Ohio

GRASS

"Grass is the forgiveness of nature,—her
constant benediction . . . Streets abandoned by
traffic become grass-grown like rural lanes
. . . harvests perish, flowers vanish, but grass
is immortal.
"One grass differs from another in glory.
One is vulgar, and another patrician—
Some varieties are useful. Some are beautiful.
Others combine utility and ornament . . ."

—From *Kansas Magazine,* vol. 2: 270-277;
1872 ("Bluegrass" by John Ingalls)

The picture on the front cover shows well-developed Kentucky Bluegrass in early June, after the stems have grown to their full length and about the close of the period of full bloom.

CONTENTS

VEGETATIVE GROWTH, DEVELOPMENT, AND REPRODUCTION IN KENTUCKY BLUEGRASS

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INTRODUCTION

This publication deals with growth, development, and certain aspects of reproduction in Kentucky bluegrass (*Poa pratensis* L.). It does not deal with seed formation. Neither does it deal to more than a slight extent with germination or viability of the seeds; these phases of the life history of Kentucky bluegrass have been studied by E. Brown (4), Pieters and Brown (25), V. G. Sprague (31), Toole (35), and others.

Piper (26, pp. 154-155) states that Kentucky bluegrass is also known as June-grass, or simply as bluegrass, and that it also has been called smooth-stalked meadow-grass. He also states that this species, native over practically all of Europe and over northern Asia and in the mountains of Algeria and Morocco, quite certainly is not native to North America. Vinall and Hein (37, p. 1039) write that Kentucky bluegrass has spread over practically all of the humid part of the United States north of the 60 degree isotherm. *Poa pratensis* and *P. compressa L.* (Canada bluegrass) occupy practically the same general region. It has been shown, however, by Hartwig (19), and by Watkins, Conrey, and Evans (38), that within the geographical area to which these two species are adapted, there are sharp demarcations in their distribution, due to differences in their soil adaptations.

Cooperative investigation by the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture and the Department of Agronomy, Ohio Agricultural Experiment Station.

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MATERIAL AND METHODS

Studies were made of individual shoots and plants of Kentucky bluegrass. Data were also obtained from square-foot areas of turf, grown from seed sown several years previously.

Most of the records of individual shoots, and of the leaves growing on them, were obtained from an area on the Ohio Agricultural Experiment Station farm at Wooster, in which ordinary commercial Kentucky bluegrass had been sown in September 1936.

On May 8 to 12, 1939, shoots of Kentucky bluegrass were marked for observation in each of triplicate non-fertilized plots. At that time each shoot, which terminated a rhizome, had only three leaves; these shoots, therefore, evidently had begun their growth early in the spring of 1939. At the beginning of the experiment, observations and records were made of 8 shoots in each plot —or of 24 in all plots. Of this number, 15 continued growth until the early summer of 1940, when inflorescences were produced on 10 of them.

The identity of the different leaves was maintained and the positions of the branches which developed in the axils of some of them were determined by having one of the leaves marked with indelible ink at a known position at all times.

Records were made of each marked shoot at 3-day intervals from May 18 to October 24, 1939, and additional records were obtained on November 7. On April 2, 1940, records were resumed and continued at 3 to 5-day intervals until some time after most of these shoots had produced inflorescences.

The study of Kentucky bluegrass in typical square-foot areas was conducted in another area which had been sown with ordinary commercial seed in August 1936. This area was later subdivided. Triplicate plots within it were fertilized at intervals with a nitrogen carrying fertilizer, as follows: On April 7 and October 13, 1937, and on April 21 and September 24, 1938, ammonium sulfate was applied at the rate of 150 pounds per acre; on April 3 and July 8, 1939, nitrate of soda was applied at the rate of 200 pounds per acre.

Alternating with these plots were others on which no fertilizer was applied. The entire area was mowed only once, about midsummer in 1937. After this time, a part of each plot went unmowed during the remainder of the experiment; on the other part, the grass was clipped with a lawn mower, at a height of about 1 inch, at intervals during 1938, 1939, and the spring of 1940.

Whenever records were to be obtained, representative square-foot areas of sod were removed to a depth of five inches, washed free of soil, and separated into shoots and rhizomes.

KENTUCKY BLUEGRASS SOD AND SOME CONDITIONS AFFECTING ITS DEVELOPMENT

After Kentucky bluegrass has become established in a sod, there is little or no further reproduction from seeds. As the older shoots and rhizomes cease growth, they are replaced by new ones which originate as branches through vegetative reproduction. Their numbers may be affected by different environmental conditions or cultural treatments.

The records presented in Table 1 of the numbers of growing shoots and rhizomes per square foot, in sets of triplicate plots, were obtained on six dates during the spring, summer, and fall of 1939, and again in April, 1940. One set of plots was unfertilized, the other fertilized with nitrogen, in the way described earlier. The effects of clipping the grass with a lawn mower are also recorded in Table 1.

TABLE 1.—AVERAGE NUMBER OF GROWING SHOOTS AND OF RHIZOMES PER SQUARE FOOT IN PLOTS OF KENTUCKY BLUEGRASS UNDER DIFFERENT CULTURAL CONDITIONS

		Not fertilized		Fertilized with nitrogen	
		Not mowed	Mowed	Not mowed	Mowed
Shoots					
1939	May 16	409			
	June 20-22	401			
	July 25-29	368	504	603	789
	August 28-30	395	541	543	816
	September 25-27	300	477	643	817
	November 27-29	300	521	706	924
1940	April 22	429	860	776	1405
Rhizomes					
1939	May 16	263			
	June 20-22	265			
	July 25-29	254	279	350	390
	August 28-30	286	321	366	401
	September 25-27	236	306	414	407
	November 27-29	252	294	498	445
1940	April 22	256	334	443	424

Number of Growing Shoots

One effect of fertilization with nitrogen was to greatly increase the number of growing shoots. Both in the unfertilized and in the fertilized plots, there was a generally larger number of growing shoots in the areas cut at intervals with a lawn mower than in the unmown areas.

Number of Rhizomes

Thêre were larger numbers of rhizomes per unit of area in the fertilized than in the unfertilized plots at all times.

In the unfertilized plots, there were somewhat larger numbers of rhizomes in the mown than in the unmown areas. In the plots fertilized with nitrogen, mowing apparently had no distinct effect upon their relative numbers.

At all times, in these plots, there were greater numbers of shoots than of rhizomes. Under the different conditions for growth, the average number of rhizomes per 100 shoots were as follows:

Not fertilized: - unmown, 72; mown, 53

Fertilized: - unmown, 63; mown, 43

THE SHOOTS

A grass shoot may begin its growth as a primary one, from seed; it may terminate a rhizome; or it may develop directly as a branch on an older shoot.

Each branch is organized from undifferentiated meristematic cellular tissue, at the base of a phytomer of the parent shoot and in the axil of the leaf that crowns the phytomer next below (14, p. 490).

If a shoot originates as a branch of a rhizome, ordinarily it begins growth as a rhizome which, sooner or later, terminates in an above-ground shoot.

In an established Kentucky bluegrass sod, a number of young shoots were marked for observation in April 1940. Half of those observed had developed from the apices of rhizomes, half as branches of older shoots. By October 31, an average of 10 percent of the terminal shoots, and 27 percent of the branches had, because of non-accidental causes, ceased growth. A shoot terminating a rhizome frequently grows in an unoccupied area, at some distance from other shoots; a branch, on the other hand, usually grows as one of a closely related group of two or more shoots, where competition for space and nutrients is likely to be greater than for a single shoot. This condition may largely explain the somewhat larger percentage of terminal shoots than of branch shoots which continued growth throughout the season of 1940. In other respects, the growth of the shoots which had originated in these two ways was essentially alike.

In the Kentucky bluegrass sod observed during 1939 and 1940, no new shoots appeared during the summer months of 1939 until about the middle of August; comparatively few appeared until early October, after which time they continued to appear in increasing numbers as autumn advanced, until growth was checked by low temperatures. Early in the spring of 1940, shoots again formed in large numbers. As spring advanced, the number of new shoots gradually diminished until soon after mid-spring, when their formation ceased. Under favorable conditions, however, limited numbers of shoots may develop during the summer.

To a limited extent at northern latitudes, and to a gradually greater extent at latitudes increasingly further south, shoots may also develop during periods of mild weather in the winter.

Position and Order of Appearance of Branch Shoots

In nearly every instance, a branch was first observed after the blade of the subtending leaf had begun to dry at the tip and before it was more than three-fourths dry. Only rarely did a branch appear after the blade was entirely dry. Of course, the branch cannot be observed until the tip of one of its leaves protrudes beyond the sheath of the subtending leaf; the time when the branch was first organized and had developed from the meristematic tissue in the leaf axil, therefore, was considerably earlier than the observations recorded here would indicate.

On shoots of a group which began their growth in the spring of 1939, no branch shoots appeared until late summer. They developed chiefly in the axils of the sixth to the ninth leaves. On shoots of another group, however, which began their growth very early in the spring of 1940, a limited number of branch shoots appeared in the axils of the first and second leaves. Apparently a branch may develop in the axil of any leaf of a Kentucky bluegrass shoots, provided that conditions are favorable for branch formation at the time when the cellular tissue in the axil of that leaf is still in a plastic condition making leaf formation possible.

If a branch does not form at a certain stage of development the meristematic tissue from which it may originate, and within a relatively limited period of time, usually none at all forms there. This statement may be illustrated by the actual positions on typical shoots of branches which developed in the autumn of 1939. Branches formed progressively, in the sequence indicated on shoot 355, in the axils of leaves 8 and 9; on shoot 356, in the axils of leaves 7, 8, and 10; and on shoot 359, in the axils of leaves 9, 10, 11, and 12.

During the first season, a shoot which begins its growth in the spring remains in a vegetative condition. Its internodes do not become elongated, and it produces leaves only.

Barren Shoots

If an inflorescence does not develop on a shoot which began its growth in the preceding season, it continues to remain in a vegetative condition, and may be said to be barren.

The internodes of barren shoots are very short. On each barren shoot, one or two internodes which develop in spring quite commonly attain lengths of about 1 to 5 millimeters; those which develop during summer and autumn do not elongate.

Repeated observations indicate that barren shoots rarely, if ever, continue their growth into the third season.

Shoots with Inflorescences

In an ordinary sod, generally only the larger and more vigorous shoots produce culms and inflorescences.

Of a number of vigorous individual shoots which began their growth in the spring of 1939 and which were observed at intervals, 44 percent of them produced inflorescences in 1940. They were then growing in a sod among other shoots, many of which began their growth in the fall of 1939 or in the spring of 1940; the actual percentage of shoots with inflorescences in these plots, therefore, was much lower than 44 percent of all shoots in the sod. In another sod along a roadside, on July 9, 1937, in three typical square-foot areas, it was found than an average of 10 percent of all the growing shoots—including the younger ones—had produced inflorescences.

The initiation and development of the inflorescences and the formation and maturing of the seed are discussed later, under the description of the inflorescences.

The Culms

In Kentucky bluegrass, the beginning of the elongation of those internodes of a stem which later constitute the culm occurs in early spring.

In the culms of 39 fully-developed shoots with inflorescences examined in June and July 1937, 5 percent of them had 3 elongated internodes; 77 percent had 4—the most common number; and 18 percent had 5 elongated internodes in the culm. Occasional culms with 6 elongated internodes have been observed.

During the earliest stages of growth of the culms, the lowest internodes are the longest, and are the first to complete their development. When the culms have attained their full length, however, the lowest or oldest internode is the shortest, and those above it are progressively longer. As shown in the records in Table 2, on June 16, on fully developed culms, the average length of the uppermost internode on the shoots examined was slightly more than one-half the length of the entire shoot. This characteristic of the growth of the culms of Kentucky bluegrass is somewhat similar to that of the culms of timothy (*Phleum pratense* L., 9, pp. 10-13), of reed canary grass (*Phalaris arundinancea* L., 13, p. 1020) and of various other grasses (27).

The lifetime of a Kentucky bluegrass shoot which has produced an inflorescence ends soon after the seeds mature, when its leaves and culm have become dry.

TABLE 2.—LENGTHS OF THE INTERMODES, IN CULMS HAVING 4 ELONGATED INTERNODES, ON SHOOTS OF KENTUCKY BLUEGRASS BEARING INFLORESCENCES

Date 1937	Number of shoots examined	Average length of internode number: 1	2	3	4	Average length of: Culm	Inflorescence	Total
		mm.	mm.	mm.	mm.	mm.	mm.	mm.
May 3	4	6.0	3.5	1.3	0.9	11.7	13.9	25.6
May 8	5	7.8	4.4	1.7	1.3	15.2	22.9	38.1
May 15	9	6.6	6.4	3.8	3.2	20.0	58.3	78.3
June 1	8	8.2	39.0	188.1	292.6	525.9	78.7	604.6
June 16	10	8.7	40.6	193.5	363.2	606.0	71.0	677.0

LEAVES

The first easily perceptible evidence of the growth of a new shoot is the appearance of the tip of its first leaf.

Number of Leaves per Shoot

The number of leaves which develop during the lifetime of a shoot depends largely upon the time when it begins and during which it continues growth. Thus, 10 shoots which began growth in the spring of 1939 averaged 16.9 leaves per shoot by the time their inflorescences had developed in 1940. Another group of 10 shoots which began growth later in 1939 and all of which produced inflorescences in 1940, averaged only 11.1 leaves per shoot.

The Plastochrone for the Leaves

Askenasy (3), 1880, defined the interval of time elapsing between the development of successive leaves as their plastochrone (14, pp. 484-485) (29).

On a number of individual vegetative shoots of Kentucky bluegrass observed during 1939 in unfertilized plots there was an average increase of 8.5 leaves in approximately 185 days—from May 8-12 to November 7-14. The average plastochrone for the leaves on these shoots, over this entire period, was about 22 days.

On a number of Kentucky bluegrass shoots which began their growth in the spring of 1939, and which produced inflorescences in 1940, the average plastochrone for the leaves which appeared on the culms from April 5 to May 10, 1940, was 11.3 days. The relatively small number of days from the appearance of a leaf until the succeeding leaf appeared on the culms of these shoots may be attributed in part to elongation of the internodes, which would tend to exsert the leaves sooner than on a vegetative shoot, the internodes of which do not become elongated. However, even on those shoots which began their growth in the spring of 1939, but which did not produce inflorescences in 1940, the average plastochrone for the leaves which appeared from April 5 to May 10, 1940, was 12.7 days—only about one day longer than the average plastochrone for the leaves which appeared during the same period, in the same plots, on those which produced culms and inflorescences. During a period in the spring, therefore, new leaves appear on the shoots of Kentucky bluegrass at more frequent intervals than during summer and autumn.

Table 3 presents the average dates when the leaves appeared, in 1939 and 1940, on three shoots of Kentucky bluegrass, each of which produced an inflorescence in 1940. From June 7 to August 14, 1939, the average plastochrones between the appearance of successive leaves was 17 days. The average date of appearance of the ninth leaf—on September 23—was 40 days later than the average date—on August 14—for the appearance of leaf number 8. The average plastochrone for leaves 10 and 11—from September 23 to November 1—was 19.5 days.

TABLE 3.—RECORDS OF THE AVERAGE DATES IN 1939 AND 1940 WHEN THE LEAVES APPEARED, AND THE FINAL AVERAGE LENGTHS TO WHICH THE LEAF BLADES GREW ON 3 SHOOTS IN NON-FERTILIZED PLOTS EACH OF WHICH PRODUCED 17 LEAVES. THE GROWTH OF EACH SHOOT, WHICH BEGAN IN THE SPRING OF 1939, WAS TERMINATED BY AN INFLORESCENCE IN 1940. DURING THE SPRING, SUMMER, AND FALL OF 1939, AND THE SPRING OF 1940, RECORDS WERE MADE AT 5- OR 6-DAY INTERVALS

Leaf number	Date leaf was first observed	Final length of blade	Leaf	Date leaf was first observed	Final length of blade
	1939	inches	number	1939	inches
1	a	1.0	10	Oct. 2	3.6
2	a	2.6	11	Nov. 1	2.7
3	a	5.8		1940	
4	June 7	7.5	12	b	2.4
5	June 22	5.8	13	April 11	1.3
6	July 6	5.9	14	April 22	1.5
7	July 29	4.8	15	May 1	1.8
8	Aug. 14	4.0	16	May 8	1.4
9	Sept. 23	4.6	17	May 20	0.7

a. Leaves 1, 2, and 3 had already developed when the first observation was made, on May 18, 1939.

b. Since records were made on only one date between early November, 1939, and early April, 1940, the average date of appearance of leaf 12 cannot be determined.

During July, 1939, there was a rainfall at Wooster of only 1.75 inches—compared with an average of 3.46 inches per month during the four preceding months. The relatively long time between the appearances of leaves 8 and 9 apparently may be attributed to the very low rainfall during July—which was followed by less than normal precipitation during August and September—in combination with the relatively high temperatures which prevail during late summer.

During late summer and winter, in the latitude of northern Ohio, where the temperatures during that time are relatively low, the time between the appearance of successive leaves is much greater. From November 1, 1939, to April 11, 1940, the average plastochrone for the leaves on the shoots recorded in Table 3 was 81 days. The average plastochrone for the 4 uppermost leaves on these shoots—numbers 14 to 17—which completed their development between April 11 and May 20—was 9.75 days.

Time During Which Leaves Remain Green and Number of Green Leaves per Shoot

After a leaf has grown to full length, its blade remains green for a time, then gradually dries from the tip to the base. About the time that the blade has become entirely dry, the sheath also has dried. The leaves become dry in the same order in which they appeared on the shoot.

The average time for each step in the processes of growth and development of the leaf blades in unfertilized plots in 1939 is shown in Table 4. On these leaves the average blade was entirely or partially green for 83 days. During the winter, however, leaves which begin growth in late fall, and which are more or less dormant at that time, usually remain green for a longer time.

During each of the growing seasons of 1938, 1939, and 1940, on each of three shoots in non-fertilized plots, there was an average number at any one time of 3.3, 3.5, and 3.4 respectively, or an average during the three seasons of 3.4 entirely green and partially green leaf blades per shoot.

TABLE 4.—AVERAGE NUMBER OF DAYS DURING WHICH THE BLADES ON LEAVES 5, 6, 7, AND 8, ON FIVE KENTUCKY BLUEGRASS SHOOTS, OBSERVED FROM JUNE 7 TO OCTOBER 29, 1939, WERE AT DIFFERENT STAGES OF THEIR GROWTH AND DEVELOPMENT

	Days
Average number of days from the time when the tips of the leaf blades appeared until their growth in length was completed	21.5
Average number of days from the time when leaf blades had completed growth until they became dry at the tip	11.2
were dry at tip until ¼-dry	16.7
were ¼-dry until ½-dry	14.2
were ½-dry until ¾-dry	9.5
were ¾-dry until completely dry	10.0
Total average number of days from the time when the leaves had appeared until their blades were completely dry	83.1

As shown in Table 5, after the young shoots had become established during their first spring's growth, the number of green leaves did not fluctuate to any great extent during the summer and fall. During the winter, the number of green leaves, especially those which were entirely green, decreased. After new spring growth had taken place in the second season, the total number of green leaves again increased to about the same number as in the preceding summer and fall. As the inflorescence approached maturity, and the leaves gradually dried, their numbers decreased.

TABLE 5.—AVERAGE NUMBER OF ENTIRELY GREEN, PARTIALLY GREEN, AND AVERAGE TOTAL NUMBER OF GREEN LEAVES PER SHOOT IN NON-FERTILIZED PLOTS, ON DIFFERENT DATES ON 7 SHOOTS, EACH OF WHICH HAD A TOTAL OF EITHER 17 OR 18 LEAVES FROM THE TIME IT BEGAN GROWTH IN THE SPRING OF 1939 UNTIL IT PRODUCED AN INFLORESCENCE IN THE SPRING OF 1940

		Average number of green leaves		
		Entirely green	Partially green	Total
1939	May 18	2.0	.6	2.6
	June 2	1.9	.7	2.6
	June 17	1.3	1.4	2.7
	July 2	1.7	1.9	3.6
	July 17	2.0	2.0	4.0
	August 1	1.9	2.6	4.5
	August 16	2.0	2.7	4.7
	September 3	1.7	2.1	3.8
	September 18	2.0	2.3	4.3
	October 1	1.6	2.3	3.9
	October 18	1.9	2.0	3.9
	November 7-14	1.7	1.9	3.6
1940	April 1-2	1.1	1.6	2.7
	April 15-16	2.1	1.6	3.7
	May 4	3.0	1.1	4.1
	May 17	2.6	1.4	4.0
	June 3	1.3	.9	2.2
	June 17	0	.3	.3

Length of the Leaf Blades

As has been shown in Table 3, the blade of the first leaf which appears on vegetative shoots of Kentucky bluegrass in the spring is short; successive ones become progressively longer. The leaves which appear during late spring and summer are relatively long. Those which appear during the autumn become progressively shorter.

On shoots which remain barren during their second season, successive leaves become progressively longer during the spring, just as on younger vegetative shoots. Thus, on the four barren shoots described in Table 6 which began their growth in the spring of 1939, the average lengths of the blades of the first three leaves which appeared in the spring of 1940 were 1.7, 3.1, and 5.7 inches, respectively.

TABLE 6.—LENGTHS OF LEAF BLADES WHICH DEVELOPED DURING EARLY SPRING IN 1940, ON BARREN SHOOTS OF KENTUCKY BLUEGRASS WHICH BEGAN THEIR GROWTH IN THE SPRING OF 1939 BUT DID NOT PRODUCE INFLORESCENCES IN 1940

Shoot number	Length of blade of the uppermost leaf which had completed its growth prior to April 1, 1940.	Final length of the 3 successive leaves, A to C, which began their growth during the period extending from approximately April 1 to May 13, 1940.		
	Inches	Inches		
		A	B	C
410	2.2	2.1	4.6	8.0
412	1.2	1.1	2.1	4.2
446	1.0	1.8	2.9	5.8
448	1.3	2.0	2.9	4.7
Average	1.42	1.75	3.12	5.67

It appears probable that the increasing lengths of leaf blades in *Poa pratensis* during late spring and early summer is a response to the gradually increasing lengths of day at that season. This hypothesis is supported by the results obtained by Stucky (33) with *Dactylis glomerata* L. and also with *Agrostis tenuis* Sibth.

On those shoots which produce inflorescences, however, as on the ones described in Table 3, the blades of the uppermost leaves which appear in the spring have successively shorter blades. Kentucky bluegrass resembles timothy (9, p. 35) in this respect. The theory of apical dominance which has been discussed by Transeau, Sampson, and Tiffany (36, pp. 250-251), and also by Meyer and Anderson (21, pp. 621-623), seems to suggest the explanation of the gradually shorter blades on successive uppermost leaves on grass shoots with inflorescences. The nutrients which pass upward through the fibro-vascular bundles of the culms seem to be directed chiefly to the rapidly developing terminal inflorescence, rather than to the lateral leaves.

THE RHIZOMES

In Kentucky bluegrass, as in some other perennial grasses (13), some of the branches assume the form of underground stems, or rhizomes, by means of which the plant gradually spreads and occupies an increasingly larger area.

The first rhizomes which develop on a young plant, such as those shown in Figure 6-A, originate from the axils of aboveground leaves. On older plants also, to some extent, rhizomes may grow from the axils of leaves, the bases of which may be just below the surface of the soil, but are not infrequently above it. A rhizome which originates from the axil of a leaf turns downward and completes its development in the soil. Most rhizomes originate beneath the surface of the soil as branches of older rhizomes.

The internodes of the rhizomes of Kentucky bluegrass become elongated. At each node there is a scale which is the morphological equivalent of a leaf and in the axil of which a branch may develop. A rhizome may branch and rebranch several times during a year (12, p. 795).

There is much variation in the number and length of the rhizomes of different plants grown under similar conditions. William L. Brown (6, pp. 721-722) reports that the variations in the rhizomes are correlated with variations in certain other parts of Kentucky bluegrass plants.

Phillippe (24) grew Kentucky bluegrass plants in replicate quartz gravel cultures in which the amounts of various elements in the nutrient solution were controlled. With 17, 57, 87, and 143 parts per million of nitrogen, the oven-dry weights of the rhizomes were 1.47, 1.65, 1.05, and 0.68 grams per plant, respectively. He found that the length of rhizomes and the number of nodes in them were in approximately the same relationship as their weights; the internode lengths were not significantly affected by the treatments used in the experiment.

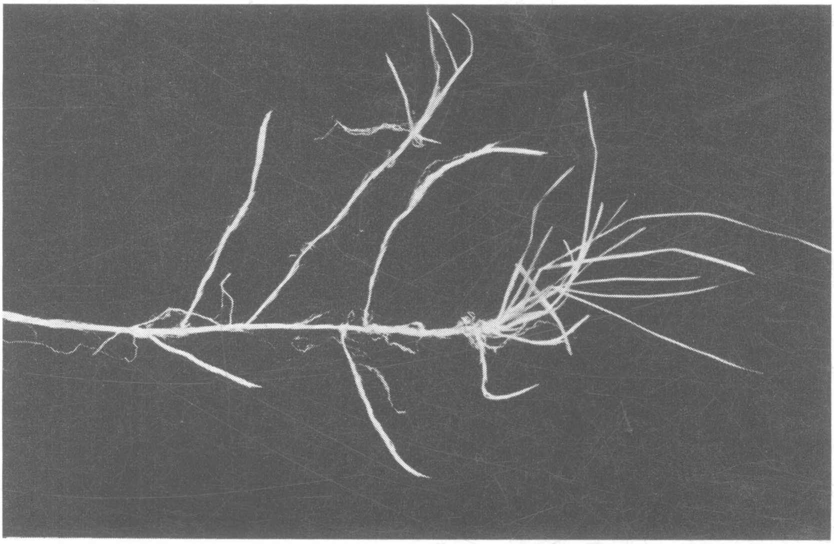

Fig. 1—A primary Kentucky bluegrass rhizome with several branches. A terminal shoot has developed on the primary rhizome and also on one of its branches.

Season When Rhizomes Develop

There were no rhizomes— at least none not terminated by shoots—on plants of Kentucky bluegrass from seed sown at Wooster in August, 1936, when they were examined on March 22-23, 1937;very few rhizomes were produced up to May 1, after which there was a rapid increase in their number (15, p. 772). In an earlier experiment, in which monthly records were made during the growing season of the numbers of new rhizomes on plants at spaced distances in cultivated rows, the largest number were recorded in June and July 1932 and in August 1933 (12, Table 1). On other plants, grown from seed sown in August 1936 and transplanted 3 by 3 feet apart in the Autumn, rhizomes developed in the greatest number from about June 1 to July 15, 1937, after which there was relatively little increase in their numbers until early October. From about October 1 to 15 the numbers of rhizomes again increased quite rapidly; after the latter date comparatively few new rhizomes formed up to November 17, when the last records were made.

These records (obtained in northern Ohio) indicate that rhizomes of Kentucky bluegrass develop in the greatest numbers during the summer under usual conditions. Harrison (18, pp. 88-89), who grew Kentucky bluegrass in glazed pots filled with sand, also observed that the active production of above-ground stems was somewhat retarded and large numbers of rhizomes develop when the days were long and bright. In late fall and early winter, however, he found that few new rhizomes were produced on plants continuously supplied with nitrogenous salts. On the other hand, plants supplied with a minus-nitrogen solution after November 10 had produced a considerable number of new rhizomes by February 1.

In studies made at the Missouri Agricultural Experiment Station during the winter of 1941-1942, many new rhizomes developed by Kentucky bluegrass growing under field conditions were observed during December and January. Few newly developed rhizomes had been observed during October and November and they appeared with decreasing frequency during February and March.[2]

Further evidence is presented later, under the discussion of photoperiodic relationships, that rhizomes develop in greater numbers under long than under short days.

When seasonal conditions become favorable, the growing point at the tip of each rhizome usually turns upward and the stem continues its growth as the axis of an above-ground shoot. The lifetime of individual shoots commonly extends through part, and less frequently through all of two successive growing seasons. The total lifetime of a rhizome and of its terminal shoot is usually less than two years.

Number of Rhizomes per Unit of Area

By November 30, 1939, there was an average stand of 202 shoots and 45 rhizomes per square foot in typical triplicate areas in a plot of Kentucky bluegrass sown in the spring of 1939. In older turfs the numbers of rhizomes, as well as the numbers of shoots (Table 1), become much larger. The rhizomes and their roots form a dense mat (Figure 2).

[2]This information was obtained by Joe Baldridge, Agent, Division of Forage Crops and Diseases, Bureau of Plant Industry, Soils and Agricultural Engineering, United States Department of Agriculture, at the Missouri Agricultural Experiment Station.

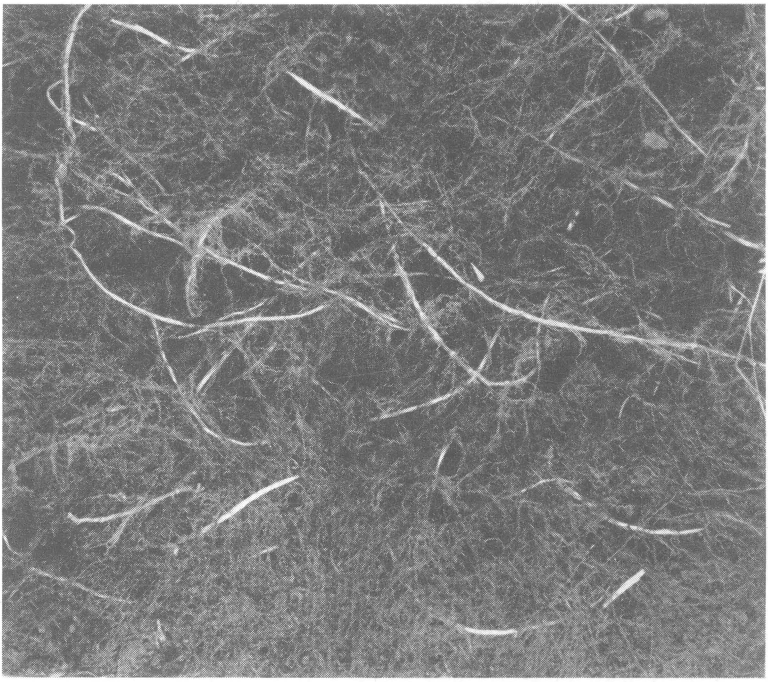

Fig. 2—Underneath an old turf of Kentucky bluegrass, dug at a depth of 5 inches, and with the soil washed away. Some of the rhizomes penetrate into the soil for more than 5 inches, though most of them grow to a depth of 2 to 4 inches. Many of the rhizomes are concealed from view by the dense mat of roots.

That fertilization or mowing may increase the numbers of rhizomes has been shown in Table 1 of this report.

Soluble Carbohydrate Content of the Rhizomes

Ahlgren (1) mowed Kentucky bluegrass at frequent intervals from early spring to autumn; at each mowing he left the grass cut at a height of 4 or 5 inches. During summer and autumn there was a constant increase in the carbohydrate reserves in the rhizomes. In non-fertilized plots for example, the starch-equivalent percentages of carbondydrates in the dry matter increased from 16.6 percent on June 27 to 27.2 percent on November 8 (the glucose equivalents are 18.2 percent and 29.9 percent respectively).

E. Marion Brown (5, p. 53) found that carbohydrate storage in Kentucky bluegrass rhizomes was most rapid after mid-October, when growth of the leafy shoots had nearly ceased.

The percentages of soluble carbohydrates were determined in samples of Kentucky bluegrass rhizomes and also of leafy shoots—not bearing inflorescences—collected at Wooster, Ohio, in 1940.[3] Total sugars in each whole sample were determined. A portion of the dried alcohol-extracted residue was boiled for 2 hours in one percent hydrochloric acid, as proposed by Spoehr and McGee (2 8-A), in order to hydrolyze additional carbohydrates. These acid-soluble polysaccharides plus the total sugars, in terms of their glucose equivalents, constitute the total soluble carbohydrates, which may be regarded as reserve materials.

In seven samples of leafy shoots of Kentucky bluegrass collected from various locations on June 25, there was an average of 27.8 percent of soluble carbohydrates in the dry matter (these samples ranged from 24.6 to 30.9 percent). On the same date, the corresponding percentages in duplicate samples of the distal, younger part of Kentucky bluegrass rhizomes was 36.2 ± 0.6, or 30.2 percent more than in the leafy shoots. The relatively high percentages of soluble carbohydrates in the rhizomes indicate their function as storage organs.

Kentucky bluegrass rhizomes were collected on July 27. The tips had not yet emerged as above-ground shoots. The average soluble carbohydrate content in quadruplicate samples of the younger, distal part of the rhizomes was 36.1 percent of the dry matter (with a range from 35.2 to 37.3 percent). The average percentage in quadruplicate samples of the older, proximal part of the rhizomes was 45.9 (with a range from 44.1 to 47.8) percent. There had been a greater accumulation of carbohydrate reserves in the older than in the younger, growing part of the rhizomes.

The greatest growth of Kentucky bluegrass herbage, as reported by E. Marion Brown (5, pp. 26-29) and others, usually occurs during late spring.

The biological and chemical data herein presented indicate that the late spring period of active above-ground growth of Ken-

[3]Walter Harris made the chemical analyses for carbohydrates, and Charles F. Rogers aided in their interpretation.

tucky bluegrass plants is followed by the development during the summer of their rhizomes and the storage of nutrients in them. These reserves become available for the development of new terminal shoots.

ROOTS

The roots of Kentucky bluegrass grow from the nodes of the rhizomes and from the basal leaf-bearing nodes of above-ground shoots.

From some distance back from the tip of an actively growing rhizome there are no roots. Records made in 1937 show that on those rhizomes which were continuing their growth underground, usually no roots had yet appeared at the 2 to 4 nodes nearest the apex. Roots had usually developed at all the nodes on those rhizomes which had terminated as above-ground shoots, however.

Stuckey (36, p. 488) found that the roots of Kentucky bluegrass, for the most part, remained functional for more than one year.

Dittmer (7) collected triplicate soil samples from an established turf of Kentucky bluegrass. After counts had been made in typical subsections of these samples he calculated that there were approximately 2,000 roots and one million root hairs per cubic inch of soil with a combined length of over 4,000 feet and a surface area of about 65 square inches.

H. B. Sprague (30) found that under the soil conditions where he studied the growth of Kentucky bluegrass, practically all roots occurred in the upper nine inches, the abundance decreasing rapidly with depth. He observed that the root system is periodically regenerated.

Naylor (23) germinated seed and grew seedlings of Kentucky bluegrass in soil having a high calcium carbonate content (pH 8.0) and in soil to which none had been added (pH 5.6). The root systems of the seedlings grown at pH 8.0 were characteristically long with few or no secondary roots. The average length of the roots was almost twice as great and the top growth of grass was 33 percent greater 90 days after planting where calcium carbonate was present than where none had been added to the soil. Root growth was definitely greater at 15° C. than at 25° C. The presence of calcium carbonate in the substrate was correlated with an evenly increased metabolic activity and growth, regardless of temperature.

In an experiment conducted by E. Marion Brown (5, pp. 47-48), the roots of Kentucky bluegrass attained their maximum growth rate at a temperature of 60 degrees F., and declined sharply as the temperature rose, practically ceasing in the lower soil levels at 80 degrees F., and in all soil levels at 90 degrees F. The production of dry matter in the tops did not appear to be seriously retarded by the reduced root growth which occurred at the 90 degree temperature. He concluded that, under natural conditions, the retarding effect of high temperature on the root growth of Kentucky bluegrass is probably a more important factor limiting the production of herbage than the direct effect of temperature on top growth.

In an unfertilized area where Kentucky bluegrass was sown in September, Willard and McClure (39) found that the underground parts—including rhizomes as well as roots—continued to increase until the fall of the following year, when they averaged about 4,000 pounds to the acre (oven-dry weight). At all times the underground parts contained a higher percentage of nitrogen than the tops. Heavy fertilization with nitrogen greatly decreased the relative amount of underground parts.

In the experiment in which Phillippe (24) grew Kentucky bluegrass plants in artificial cultures, root development was reduced by high levels of nitrogen. In the cultures containing 17, 57, 87, and 143 parts per million of nitrogen, the oven-dry weights of the roots were 3.70, 3.11, 2.49, and 1.90 grams per plant, respectively.

INFLORESCENCES

The vegetative growing point of a shoot of Kentucky bluegrass, having on it several encircling ridges, is illustrated in Figure 3-A. As new leaves develop progressively from the older basal ridges, in the same order that the latter had appeared, additional ridges are initiated distichously, in the apical region of the growing point. Since the plastochrone for the formation of new ridges is somewhat shorter than for the development of leaves, there is a gradual accumulation of an increasingly larger number of these ridges in the vegetative growing point.

At the time when an inflorescence begins its development from the same growing point from which leaves had been developing previously, swellings, or secondary protuberances, also with a

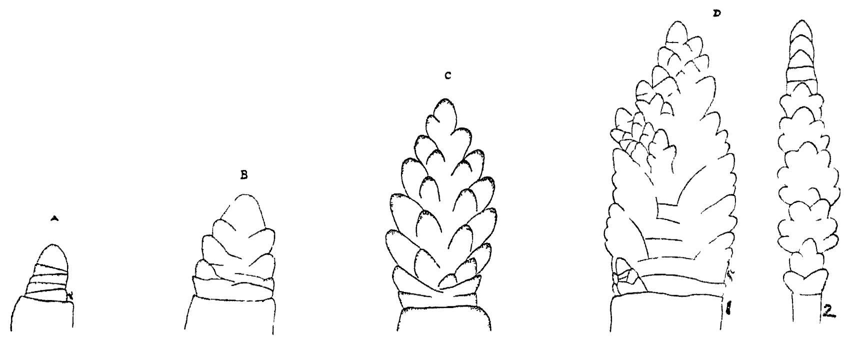

Fig. 3—The growing point of a vegetative shoot and of rudimentary inflorescence of Kentucky bluegrass at different stages of development. A, B, C, and D-1 are viewed at right angles to, and D-2 is viewed in the same plane as the leaves of the shoots.

A a vegetative growing point.

B. therudimentary inflorescence beginning to form, with several secondary protuberances.

C. tertiary protuberances forming on the older secondary ones.

D-1. rudimentary inflorescence, partly in outline, in which quaternary protuberances have formed.

D-2. the face of the drawing shows the right edge of the same rudimentary inflorescence shown in D-1.

distichous arrangement, like those shown in Figure 3-B appear. As the protuberances continue their development, further growth of the ridges is suppressed. In mature inflorescences a few slight ridges may be detected, subtending the lower groups of spikelets, or they may have become entirely obliterated. In Kentucky bluegrass, as in many other grasses (14, pp. 514-515), the first protuberances arise about at—or slightly below—the middle of the growing point, and later ones form in basipetal as well as in acropetal succession. These secondary protuberances have the same relative positions on the primary axis of the shoot as the vegetative buds and are their homologues.

As development continues, tertiary protuberances, like those shown in Figure 3-C, originate from the secondary ones. In the larger and more vigorous rudimentary inflorescences, quaternary protuberances, like those shown in Figure 3-D and possible protuberances of an even higher order, may develop.

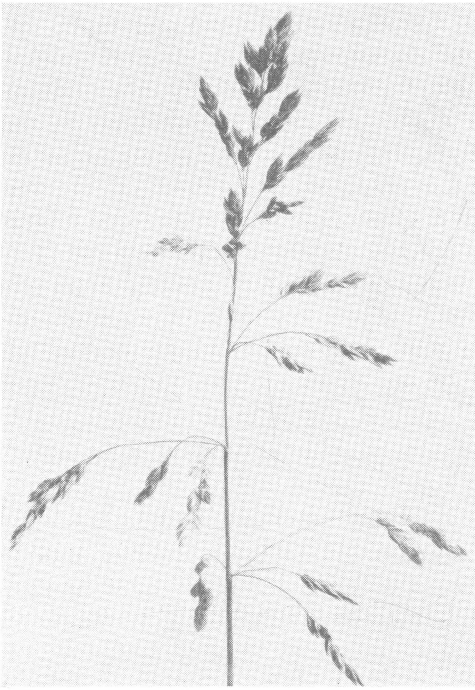

Fig. 4—A fully developed inflorescence of Kentucky bluegrass. The groups of branches developed from an apical and from lateral protuberances, such as those illustrated in figure 3-B.

From each secondary protuberance, such as those shown in Figure 3-B, a branch or a group of branches eventually develops. As their axes grow in length, the internodes of the primary shoots also elongate to form the rachis of the inflorescence. On it the groups of branches are arranged, alternately and on opposite sides—that is distichously—as shown in Figure 4.

On some plants growing in cultivated rows, 90 percent of the shoots on which six leaves had developed by November 18, 1931, produced inflorescences in the spring of 1932. On the same plants, none of the shoots on which only two leaves had developed by May 12, 1932, produced an inflorescence in that season. Since the inflorescences are initiated during the winter months, as is shown in the following discussion, it is obvious that all shoots which produce inflorescences must begin their growth in the preceding year.

Time of Initiation and Development of the Inflorescence

In order to determine when the inflorescences are initiated, some of the larger and more vigorous shoots from plants which had been transplanted to cultivated row plots were studied during the winter of 1941-1942. An early, a medium-late, and a late strain were used. The plants were propagated vegetatively from the same original plants, and they represent the same strains used in an earlier experiment, in which their responses to different lengths of day were studied and described by Allard and Evans (2, pp. 201-203).

Growth in length of the rudimentary inflorescences of the early strain was gradual and quite consistent throughout the winter. Their average lengths on various dates were approximately: December 29, 0.8 m.m.; January 26, 1.00 m.m.; February 23, 1.20 m.m. 5; March 23, 1.70 m.m. The approximate average lengths of the rudimentary inflorescences of the late strain on the same dates were 0.5, 0.5, 0.6, and 0.9 m.m. respectively. In both the medium-late and the late strains, there was only a slight increase in the lengths of the rudimentary inflorescences until about the middle of February. After about March 10, the rate of growth in the lengths of all strains became accelerated.

The lengths of the growing inflorescences of Kentucky bluegrass at later times in the spring—as recorded in another study—have been shown in Table 2.

A preliminary examination of the shoots of all strains had been made on November 23, 1941; the growing points of all shoots were then in a vegetative condition. By December 18 to 19, however, it was found that protuberances had begun to form on many shoots of the early strain and also on a small portion of the shoots of ordinary Kentucky bluegrass.

From 6 to 10 of the larger and more vigorous shoots of each strain were dissected at weekly intervals from December 22 to March 23. On one or more occasions, the examination of the shoots occurred when the temperature was below zero. Under this condition, the growing points were flaccid and could be dissected only with great difficulty. When outdoor temperatures were above freezing, the growing points again became turgid.

The condition of the growing points or of the rudimentary inflorescences of the various strains used in this study are described in Table 7.

On December 22, when 83 percent of the growing points of the early strain had protuberances, all of the growing points of the late strain were still vegetative. A little more than a month later, on January 26, protuberances had developed on 90 percent of the growing points of the late strain. By this time some tertiary protuberances had formed on all strains, and 10 percent of the early ones had quaternary protuberances. At all times during the winter the early strain was more advanced than the late one. In general,

TABLE 7.—DEVELOPMENT OF THE GROWING POINTS OR RUDIMENTARY INFLORESCENCES OF AN EARLY, A MEDIUM-LATE, AND A LATE STRAIN OF KENTUCKY BLUEGRASS, AT WEEKLY INTERVALS DURING THE WINTER OF 1941-1942.*

	Percentage of growing points at various stages of development											
	Early				Medium-late				Late			
	V	S	T	Q	V	S	T	Q	V	S	T	Q
1941												
Nov. 23	100				100				100			
Dec. 22	17	33	50		50	33	17		100			
Dec. 29		17	83		33	67			62	38		
1942												
Jan. 5		17	83		60	40			50	50		
Jan 12			100			100			30	70		
Jan 19			100			50	50		50	50		
Jan. 26			90	10		90	10		10	80	10	
Feb. 2			100			33	67			80	20	
Feb. 9			80	20		40	60			75	25	
Feb. 16			10	90		10	90			80	20	
Feb. 23			50	50		33	67			70	30	
Mar. 2			67	33		20	80			67	33	
Mar. 9			90	10		20	80			50	50	
Mar. 16			10	90			100				90	10
Mar. 23			10	90			70	30		20	60	20

V indicates that the growing points were in a vegetative condition. S, T, and Q, indicate that secondary, tertiary, and quaternary protuberances, respectively, had begun to form.

the growing points of the medium-late strain were at an intermediate stage, but were more nearly the condition of the late than of the early one.

On less vigorous shoots which had been somewhat delayed in development, rudimentary inflorescences were found on which only secondary protuberances had formed by April 10. Vegetative growing points may be found on young or on barren shoots at all times of the year.

The Development of the Spikelet

After the formation of protuberances of successively higher orders has proceeded to approximately the stage shown in Figure 3-D, this phase of development ceases; no more protuberances, from which spikelets might develop, appear.

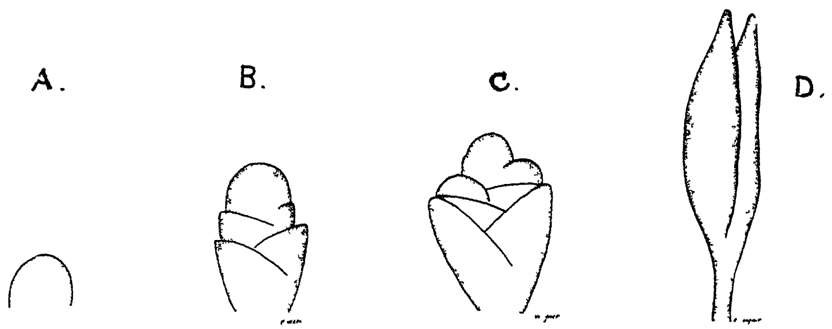

Fig. 5—Different stages in the development of a spikelet:

A. A protuberance from an axis of a rudimentary inflorescence.

B. A rudimentary spikelet with the beginning of the two glumes and 2 lemmas.

C. In the axils of the 2 lower lemmas protuberances which represent the beginning of florets have formed.

D. The 2 glumes have completed their growth in length and have hidden the the florets from view.

A spikelet begins to develop at about this time from each individual protuberance which has previously formed, such as the one shown in Figure 5-A. Its first indication is the appearance of a lateral ridge—the beginning of the lower one of the two glumes. Then the second glume, and above it, in distichous order, the lemmas appear (Fig. 5-B). In the axils of each of one or more lemmas other protuberances, which are the beginnings of florets, develop (Fig. 5-C). Soon the glumes grow more rapidly in length, and conceal the developing florets of the spikelet (Fig. 5-D). A seed may form from each floret.

Emergence of the Inflorescence from the Enclosing Leaf Sheaths

With reference to grasses in general, Evans and Grover (14, p. 491) state that at the time when an inflorescence emerges from the enclosing leaf sheaths, its organization and most of its development have been completed.

At the Timothy Breeding Station, North Ridgeville, Ohio (41.4 degrees north latitude), on marked shoots of *Poa pratensis* which began their growth in 1931, the average date when the inflorescences appeared was on May 17, 1932. The corresponding date for similar shoots of *Bromus inermis* Leyss was May 31; for *Poa compressa,* June 1; for *Phalaris arundiancea,* June 5; for *Agrostis alba,* June 11, and for *Phleum pratense,* June 12.

Flowering Habits

Flowering usually begins a little more than 2 weeks after the inflorescences have appeared. The time of flowering, like that of the emergence of the inflorescences, occurs earlier in Kentucky bluegrass than in other perennial grasses common in the northeastern states. At the Timothy Breeding Station, North Ridgeville, Ohio, the average dates in 1932 when the first florets bloomed in row plots of different species grown from ordinary commercial seed were: *Poa pratensis,* June 5; *Phalaris arundinacea,* June 15; *Bromus inermis,* June 21; *Poa compressa,* June 23; *Phleum pratense,* June 30; *Agrostis alba,* July 2.

In fields of ordinary Kentucky bluegrass, florets bloom during a period of about 10 to 12 days, sometimes slightly longer.

According to Fruwirth (16), the flowering process of Kentucky bluegrass begins in the upper part of the inflorescence. He observed that the florets of Kentucky bluegrass usually begin to bloom about 4:00 to 5:00 a.m.; that most of the florets are in bloom from about 5:00 to 6:00 a.m., and that some may continue to bloom until from about 9:00 until as late as 11:00 a.m. Some florets, he observed, may bloom about 5:00 to 6:30 p.m. He found that the process of blooming may be checked by unfavorable weather, such as low temperature or rain.

There is considerable variation in the time when plants representing different biotypes of the species are in bloom. In the experiment conducted by Allard and Evans in 1936 (2, pp. 201-203), on plants growing under natural conditions in the field, at Arlington, Virginia (38.9 degrees north latitude) the first florets in bloom were observed on the early strain April 25; on the medium-late strain by May 4; and on the late strain May 11.

The time of blooming varies in different seasons. In 1937 at Wooster, in plots of the early strain of Kentucky bluegrass to which reference has been made, florets were in bloom in considerable numbers from June 1 to June 7. The corresponding period of blooming in 1938 was about 12 days earlier—from May 20 to May 27. In 1937, the mean temperature for March, April, and May were 33.0°, 47.6°, and 58.5°, respectively, with an average mean for the entire period of 46.4° F. In 1938, the corresponding mean temperatures for these months were 43.0°, 49.9°, and 59.1°, with an average mean temperature of 50.7° F. during the 3-month period, or

4.03° above those for 1937. Similar seasonal variations in time of blooming associated with seasonal variations in temperature occur in timothy (10, pp. 213-214).

Seed Formation

The problems of seed formation in Kentucky bluegrass were not dealt with in this investigation. They have been studied by Engelbert (8), Fruwirth (16, Table 3), Muntzing (22), Smith and Nielsen (28), Tinney (34), and by others.

Maturing of the Seed

Some records were made in several seasons at New London, in northern Ohio, of the time when the glumes on the inflorescences and the upper parts of the culms had become straw color; this occurs at about the time the seed has matured. Kentucky bluegrass was observed to be in this condition on June 21, 1912; July 1, 1913; June 24, 1914; and July 6, 1915.

Garman and Vaughn (17, p. 37) state that in Kentucky—about 3 degrees south of northern Ohio—Kentucky bluegrass seed matures from about June 15 to 20. When seed is harvested before it is fully mature, they found that it more readily becomes heated during the curing process, which results in a reduced percentage of viable seeds. On the other hand, King (20, p. 8) states that after the seeds have matured, a rather short period intervenes before they begin to shatter; the amount of shattering is greatly increased by heavy rain or hail, and seed crops may even be lost completely through these unfavorable conditions.

PHOTOPERIODIC RELATIONSHIPS

Various phases of growth, development, and reproduction of Kentucky bluegrass are affected by differences in day lengths—that is, by different photoperiods.

Upright or Decumbent Position of Shoots in Relation to Day Length

Under natural conditions, during late spring, summer, and early autumn, the shoots of Kentucky bluegrass grow in a generally upright position; during late autumn, winter, and early spring they are more or less decumbent (Fig. 6).[4]

[4]Figure 6 is used through the courtesv of the Journal of the American Society of Agronomy.

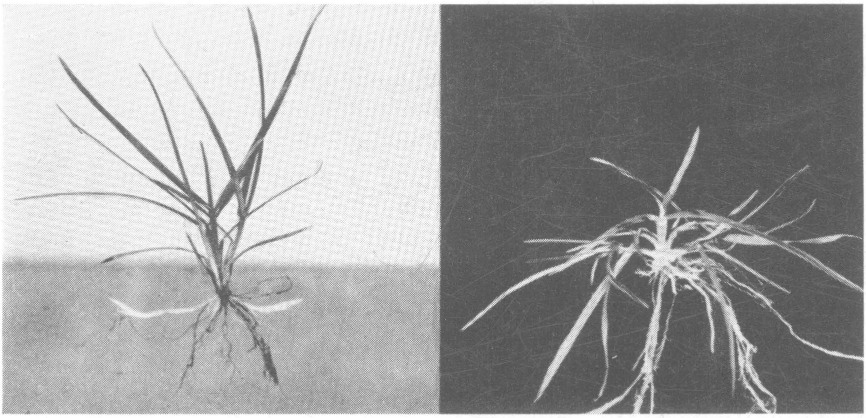

Fig. 6.—Typical young plants of Kentucky bluegrass, in summer and in winter.

A. A plant photographed in July, 1937. The shoots and leaves are growing in a generally upright position. Two rhizomes have developed.

B. Plant photographed in March, 1937. The shoots and leaves are growing in a relatively decumbent position. There are 14 vegetative shoots, but no rhizomes on this plant.

Stuckey (32) found that when *Dactylis glomerata* and *Agrostis tennuis* Sibth were grown under short days the stems were more or less decumbent; when grown under long days, they were upright. Similar results have been obtained with Kentucky bluegrass when it has been grown under these conditions of daily illumination during the spring months (2, 15).

This experiment with Kentucky bluegrass was repeated in late summer and autumn (15). Plants from seed sown on August 19, 1937, were grown until November 26 under day lengths extended by means of artificial lights to 18 hours; other plants were grown during this time, under day lengths reduced by means of dark boxes to 8½ hours daily illumination. Under the long day the shoots grew upright; under the short day they were decumbent (Fig. 7).

The fact that the stems and leaves of Kentucky bluegrass were decumbent under short days, even during the warm weather of late June and early July, and that they grew in an upright position under the longer days, even during the cool weather of late November, suggests that length of day had a greater influence than temperature upon this phase of the growth of the plants.

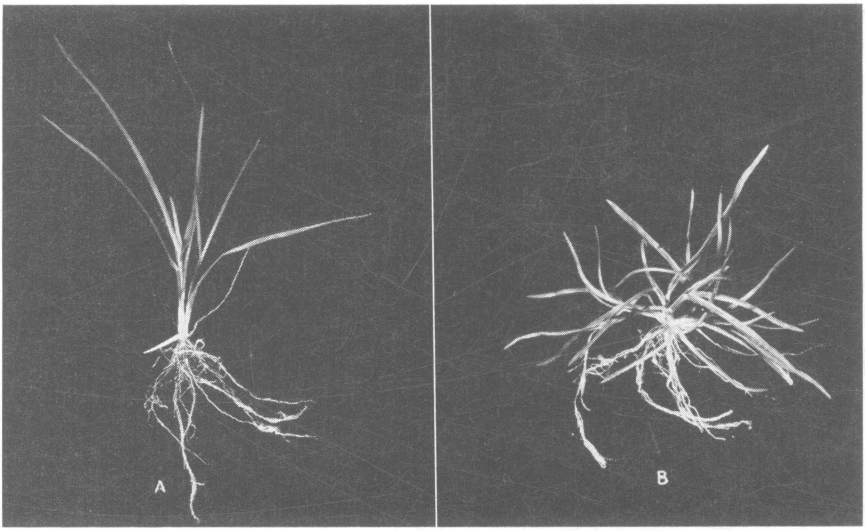

Fig. 7—Kentucky bluegrass plants grown from seed sown August 19 and photographed on November 24, 1937.

A. A plant grown with 18.0 hours daily illumination.

B. A plant grown with 8.5 hours daily illumination.

Number of Shoots Under Short and Under Long Days

In the experiment conducted at Wooster in the spring of 1937 (15, Tables 1 and 2), only 33 percent as many shoots per plant developed under 18 hours as under 8½ hours daily illumination. When the experiment was repeated in the autumn, the number of shoots under the long day, again, was only 38 percent as great as under the short day. Length of day appeared to have a greater influence upon the number of shoots, as well as upon the position at which they grew, than did the differences of temperature during late spring compared with those during late autumn.

Formation of Rhizomes Under Different Lengths of Day

In the experiment conducted in the spring of 1937, on plants grown from seeds sown in the preceding summer, the ratios of shoots to rhizomes were 100:67 and 100:190 under short and long days, respectively. The corresponding ratios were approximately 100:2 and 100:17 on younger and smaller plants grown during the autumn of 1937, under the same day lengths. At both seasons, a larger proportion of the total number of branches developed in the form of rhizomes when the plants were grown under long days than when they were grown under short days (15, Tables 1 and 2).

Development of the Inflorescence as Affected by Photoperiods

In regard to the time when the inflorescences emerged and the florets bloomed in the experiment with Kentucky bluegrass conducted at Washington, D. C., there was no clear-cut, regular relation to the lengths of day under which they were grown (2, Table 3). In this respect Kentucky bluegrass differed greatly from timothy, grown in another experiment (11), in which these processes occurred gradually earlier as the length of day was increased, by intervals, from the minimum used up to the optimum for each strain grown. The lack of definite relation of time of heading and blooming to day lengths of 10 hours or more in Kentucky bluegrass may be attributed to the fact that in this species the inflorescences are initiated during the short days of winter, instead of during the days of increasing lengths in the spring, as in timothy and some other perennial grasses (14, p. 491). The inflorescences of Kentucky bluegrass were already partly developed before the length-of-day experiment was begun.

THE ANNUAL CYCLES OF GROWTH, DEVELOPMENT AND REPRODUCTION

The preceding records show that there is a definite relationship between the characteristic habits of growth of Kentucky bluegrass in summer and the long days which occur then, and the different habits of growth of the plants in winter and the short days at that time.

Leaf Growth Continuous Throughout the Year

Leaf formation on plants of Kentucky bluegrass continues throughout the year, excepting (especially in northern latitudes) when the plants are dormant during periods of low temperature in winter. Leaf growth may also cease during periods of extremely hot, dry summer weather.

Periods When Vegetative Reproduction Occurs Through New Shoots and Rhizomes

As the older shoots and rhizomes complete their growth, the continuation of the life processes of the plant is made possible through the vegetative reproduction of new branches.

The correlation between days of short to medium lengths and the formation of leafy shoots, and of medium to long days and the formation of rhizomes, is indicated in Figure 8. This illustration also indicates that there is some correlation between temperature and the type of branches which develop. In northern Ohio, chiefly leafy shoots develop in early spring and late autumn when the average temperatures range from about 35° to 50° F. During the summer, when average temperatures range from about 60 to 70 degrees or more, chiefly rhizomes develop. In late spring and

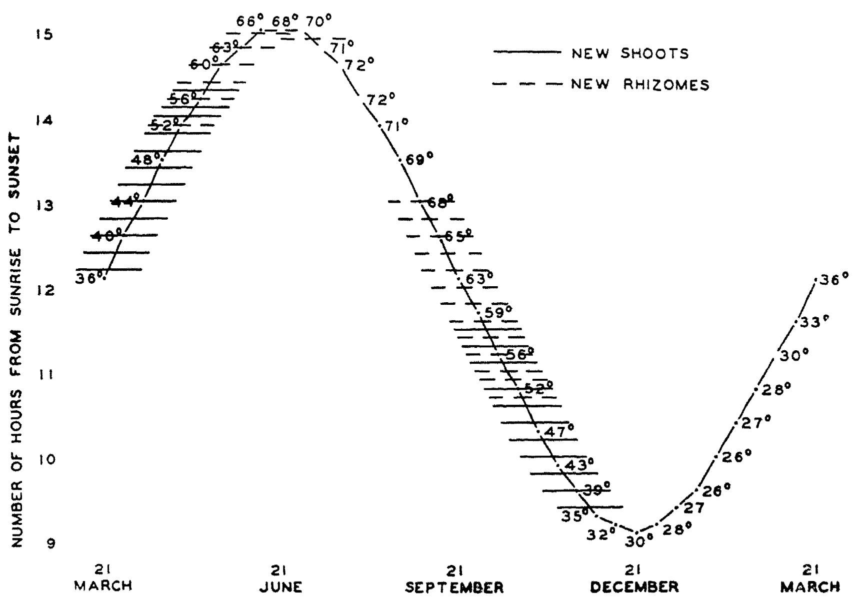

Fig. 8—Periods during which new shoots and rhizomes form on plants of Kentucky bluegrass. The lengths of day are indicated by the curve. The Mean temperatures in degrees F. on the 1st, 11th, and 21th of each month, indicated by dots in the curve, are also shown. These temperatures are based on records for 46 years at the Cleveland, Ohio, U.S. Weather Bureau Station, which is about 50 miles from Wooster.

early autumn, when the average temperatures range approximately between 50 and 60 degrees, both shoots and rhizomes develop. When the average temperatures fall to less than about 35 degrees, few new branches of either type appear.

The season when leafy shoots develop in the largest numbers (from about mid-autumn to mid-spring) and the season when rhizomes usually develop in the largest numbers (from about mid-spring to mid-autumn) are indicated in Figure 9, in different parts of the middle circle, which is just outside of the continuous inner one which indicates that leaf formation occurs at all times when weather conditions permit. To some extent, the two parts of the circle which indicates when leafy shoots and when rhizomes develop, overlap. Together they continue to form throughout the year, except for interruptions due to unfavorable conditions: at northern latitudes the formation of shoots is retarded or suppressed more or less in winter by low temperatures; rhizome formation also sometimes may be retarded by unfavorable summer conditions, as when very high temperatures prevail (5, p. 27).

The different periods during which shoots and rhizomes generally develop on plants of Kentucky bluegrass, as they grow at about the latitude of northern Ohio, are illustrated in Figures 8 and 9. Data which have been presented show that exceptions sometimes occur. When either shoots or rhizomes develop in considerable numbers out of their usual season, probably this occurrence may be attributed to some unusual, not well understood, combination of and interaction among varying environmental factors such as day lengths, temperatures, soil moisture, and plant nutrients.

Time of Initiation and Development of the Inflorescence

The development of the inflorescences of Kentucky bluegrass begins in northern Ohio in very late autumn or in early winter, when the shortest days of the year occur. By the latter part of March or possibly early April, the process of initiation of the inflorescences—as indicated by the formation of protuberances—is completed. Beginning about early April further development of the spikelets, florets and seeds gradually takes place. After the seeds have fully matured, in late June, the process of reproduction through the inflorescence, as indicated by the outer semicircle in Figure 9, has been completed.

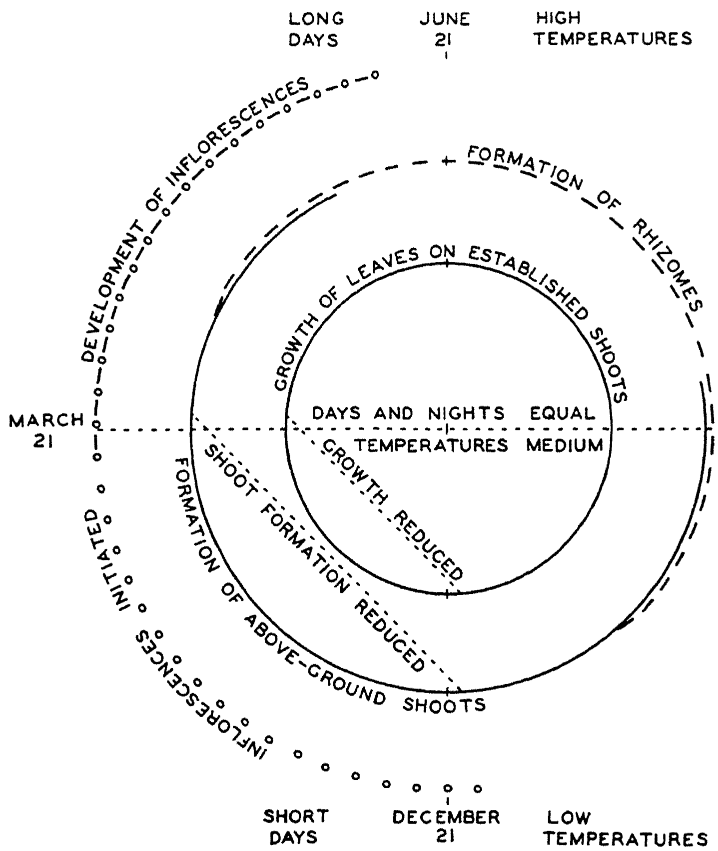

Fig. 9—The annual cycles of leaf growth, vegetative reproduction through the development of branches, and reproduction through the inflorescence, in Kentucky bluegrass as it grows in northern Ohio. Since the life processes of the plants are modified by varying environmental condition, the limits of the duration of each phase of growth, development and reproduction, as illustrated here, can be only approximation.

The facts which have been presented suggest that the reason why no inflorescences appear on plants of Kentucky bluegrass during late summer or autumn, as on plants of timothy (9, p. 41) and of some other perennial grasses, may be that the short days which this process requires do not occur at the time when the inflorescences would be initiated.

SUMMARY

A study was made of growth, development, and reproduction in Kentucky bluegrass (*Poa pratensis* L.)

Fertilization with nitrogen or clipping at intervals with a lawn mower resulted in increased numbers of leafy shoots. The numbers of rhizomes per unit of area, also, were increased, although to a less extent than the number of shoots, by each one of these cultural treatments.

The formation and growth of leaves on established shoots continue throughout the year, excepting that these processes are much reduced by low temperatures during the winter months. The leaves grow to greatest lengths during late spring and early summer. The total number of leaves which develop during the lifetime of a shoot varies—depending largely upon when it begins growth: on observed shoots which produced inflorescences the total number varied from about 11 to 18. The blade of each leaf remains entirely green for a time, then becomes dry at the tip, and finally becomes entirely dry. On a number of shoots which completed their growth during spring, summer, and autumn, the average time from when the tip of the leaf appeared until it had become entirely dry was 83 days. As new leaves develop progressively in distichous order from the growing point, the older ones gradually become dry in the same order. The average number of growing leaves on a shoot at any particular time ordinarily ranged from about 3.5 to 4.5.

A shoot which begins its growth in one season may produce an inflorescence which terminates it in the following spring. If a shoot remains barren, it may continue vegetative growth for a longer time. Most, or all, of these barren shoots usually cease growth at some time during their second season.

After a Kentucky bluegrass sod has once developed from plants grown from seed, further reproduction of new shoots, which replace those which have ceased growth ,takes place from the apices of rhizomes and from the axils of leaves of older shoots. New shoots develop chiefly during that time of the year when days are relatively short—most of them from about mid-autumn until

about mid-spring—except when this process is reduced by low winter temperatures.

Most of those branches which develop from about mid-spring to mid-autumn, when days are relatively long, assume the form of underground rooting stems or rhizomes. Rhizomes usually develop from the axils of the scales of older rhizomes. Less frequently they develop from the axils of the leaves of above-ground shoots; from this position they turn downward and penetrate into the soil. During the late spring and summer they contain relatively high percentage of soluable carbohydrates. When days become shorter during the autumn, the apices of most of them turn upward and terminate in above-ground shoots.

When an inflorescence forms, it develops from the same apical growing point of the shoot from which the leaves have previously grown. The first evidence of the initiation of the inflorescence is the appearance of protuberance. The earliest ones are arranged distichously on the central axis, each of the lower ones being in the axil of a ridge, that is, a rudimentary leaf. The first protuberances in Kentucky bluegrass form in late December or early January. During the winter, branch protuberances of higher orders develop from each one. Glumes, lemmas, and florets form on each protuberance in the spring and a spikelet develops from it.

In the latitude of northern Ohio, the inflorescences emerge from the enclosing leaf sheaths at approximately the middle of May. About 2 weeks later the florets bloom. The seeds mature during the latter part of June.

During late spring, summer, and early autumn, the shoots and leaves of Kentucky bluegrass grow in a generally upright position. During late autumn, winter, and early spring they are decumbent. If the plants are grown during spring and early summer—or at any other time—under daily illumination artificially reduced to 8 or 9 hours, the shoots and leaves tend to be decumbent; if grown in late autumn—or at any other time—under daily illumination extended to about 18 hours, the shoots and leaves are upright. These reactions to days of different lengths indicate that the different habits of growth of the plants at different seasons are largely due to their susceptibility to photoperiodic influences.

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